HEAVY MINERAL ANALYSIS OF SELECTED MONTEREY BAY CORES

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THESIS

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March 1971

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ABSTRACT

This study was conducted to identify heavy minerals and their changes with depth in three cores taken from different locations in Monterey Bay, California. Monterey Bay provides an area where several different sources influence the sediment deposition.

Minerals indicative of the geological formations in the drainage areas of the Pajaro and Salinas Rivers were found in distinctive distribution throughout these cores. Glaucophane, indicative of the Franciscan Formation, was found near the bottom of all cores. The larger percentages of augite found in the core at Santa Cruz were probably derived from the north due to longshore drift. High percentages of garnet and low percentages of hypersthene with depth in the Moss Landing Core reflect the influence of the Salinas River.

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In addition, appreciation is expressed to T. E. Yancey of University of California for his recent personal communication on further findings in this area of study, to LT. K. J. Hermann, USN, for his previously-conducted textural analyses of the cores used, and to Naval Postgraduate School Educational Media Department for all services rendered.

Further sincere appreciation is given to my wife for her critical reading of my drafts.

I. INTRODUCTION

A. OBJECTIVE

Numerous studies have been conducted in order to define heavy mineral assemblages in the coastal sands of California. These studies have been directed not only toward beach sand analysis but also toward continental shelf sands and sediments. However, few of these studies have been directed toward analyzing heavy mineral changes with depth in a core sample of the sediments with the purpose of defining possible changes in drainage patterns in a given area.

Monterey Bay provides a region of interest where several drainage areas may be defined by heavy mineral assemblages. The sediments in the northern part of the bay are affected by the outflow of the Pajaro River, Soquel Creek and San Lorenzo River (Fig. 1). The sediment deposition pattern is broken by Monterey Submarine Canyon. In the southern portion of the bay, sediments are predominantly influenced by the Salinas River outflow since there has been, at least in recent periods, only minor transport across the head of the canyon.

The objective of this research has been to identify heavy minerals and their respective changes with depth in three cores taken in Monterey Bay aboard the M.V. OCEANEER during the period 28 February to 2 March 1970. The primary purpose of the sampling was to obtain long sediment cores in Monterey and Carmel Bays through the use of a 20-ft hydraulic powered vibratory corer designed by Ocean Science and Engineering, Inc.,

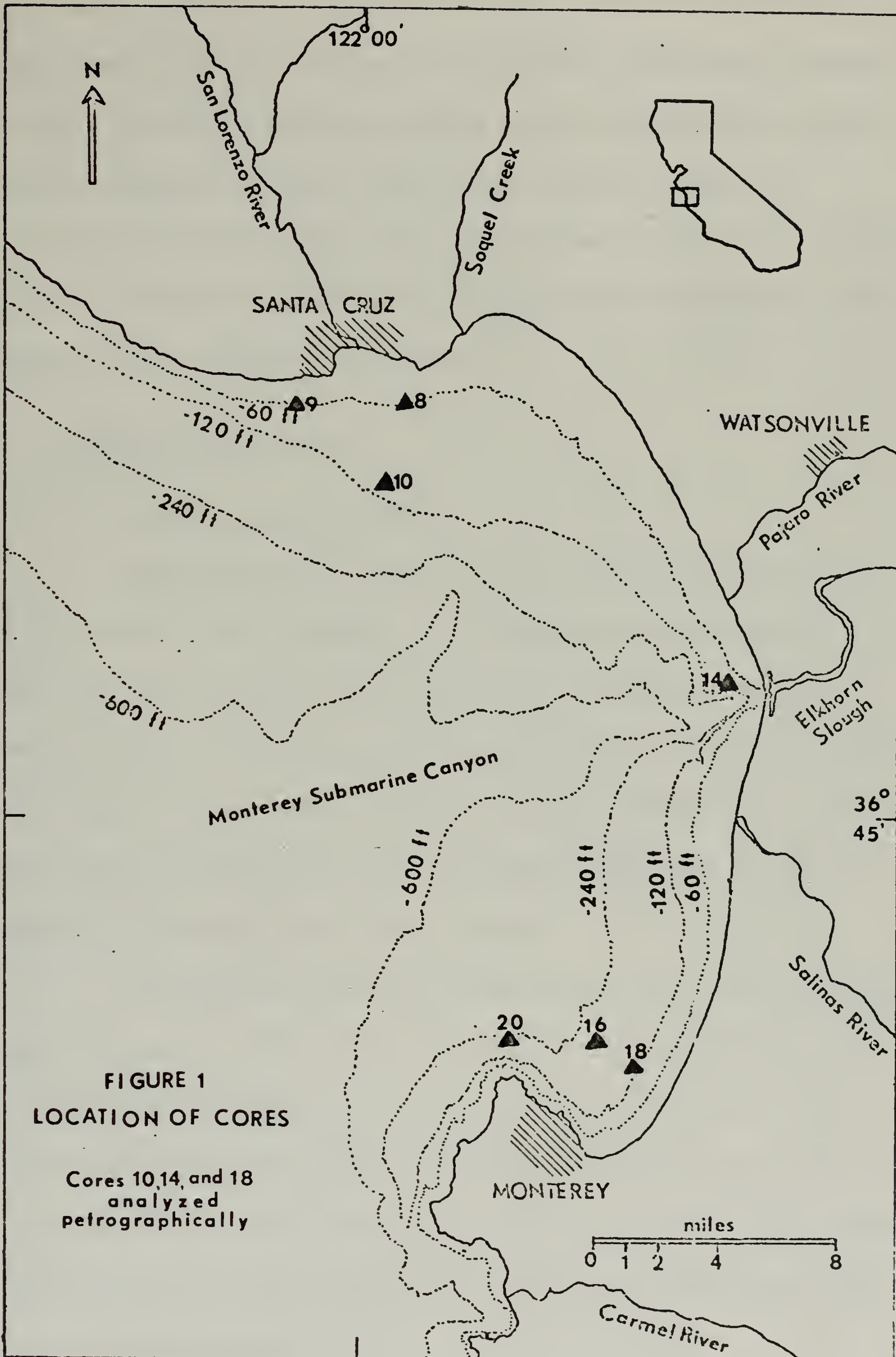


FIGURE 1
LOCATION OF CORES

Cores 10,14, and 18 analyzed petrographically

Long Beach, California. There were several other cores (varying in length from 0.5 to 21 feet) taken on this cruise, but the ones analyzed for heavy minerals in the present study were considered most typically located to define the various sedimentary provinces of the bay.

Textural analysis of all of the cores shown in Fig. 1 was performed by LT. K. J. Hermann, USN, as a research project at the Naval Postgraduate School, Monterey, California.

B. GENERAL DESCRIPTION

1. Geology and Hydrology

Monterey Bay is located on the central California coast 70 miles south of San Francisco. Its northern half experiences longshore drift from the north, but at the southern extremity a prominent headland exists. The bay is divided by the Monterey Submarine Canyon which heads nearshore in the center of the bay. Smooth depth contours characterize a great portion of the continental shelf area in the bay except where the Monterey Canyon appears.

San Lorenzo River and Soquel Creek empty into the northern portion of the bay. Both of these streams have small drainage areas in the Santa Cruz Mountains of 140 square miles and 25 square miles, respectively (Hendricks, 1964). The Ben Lomond area of the Santa Cruz Mountains, which is the drainage area of the San Lorenzo River, contains granitic and metamorphic rocks as well as Miocene and Tertiary sedimentary formations (Fig. 2).

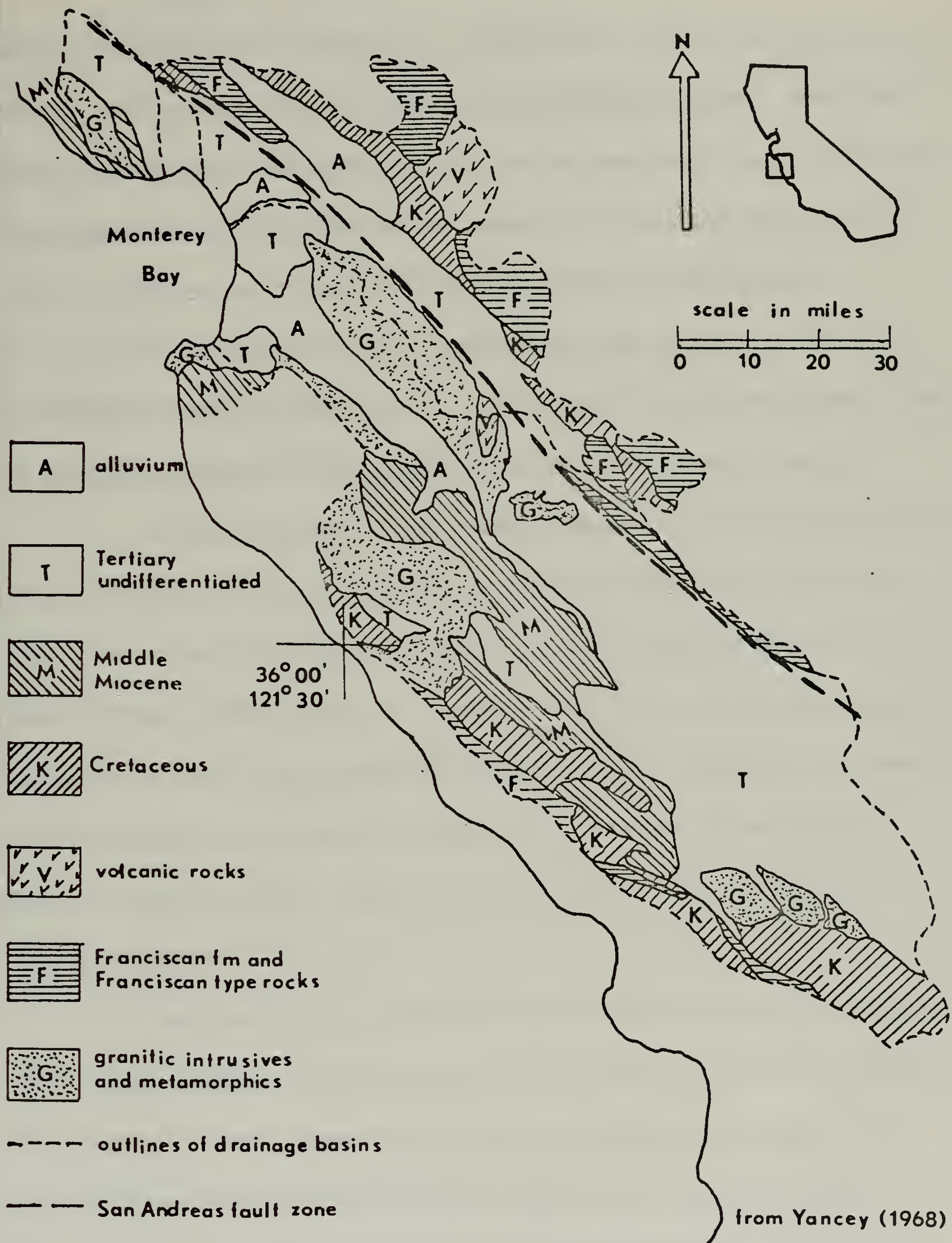


FIGURE 2
GENERALIZED GEOLOGY OF THE MONTEREY BAY DRAINAGE BASINS

Pajaro River flows into the north-central portion of the bay north of Elkhorn Sough and drains a considerable area of the Santa Clara Valley. Pajaro River and its tributary, the San Benito River, carry sediments derived from a number of geological formations. Franciscan rocks are exposed on the west side of the Santa Clara drainage basin (Yancey, 1968) and exposures of granitic rocks are extensive in this area. Granitic or Franciscan rock types everywhere form the basement rock of the drainage area of Monterey Bay, but over most of the area these types are deeply covered by Cretaceous and Tertiary sedimentary rocks.

Elkhorn Slough, a salt-water embayment, presently provides little sediment to the bay. Shepard and Emery (1941) suggest that the Salinas River may have emptied through Elkhorn Slough in the recent past. Dorman (1968) noted that prior to 1906, navigation charts showed the Salinas River emptying through Elkhorn Slough. Starke and Howard (1968) reported the presence of a deep buried canyon in the area of Elkhorn Slough extending inland from and aligned with the Monterey Submarine Canyon.

Salinas River, south of Elkhorn Slough, drains an extensive area to the southeast of Monterey Bay. Included in this area are portions of the Gabilan Range, Santa Lucia Range and Sierra de Salinas. The Gabilan Range and most of the Santa Lucia Mountains are formed of quartz diorites, quartz monzonites, and metasediments. The Salinian Block which composes the majority of the basement rock is of the same rock assemblage. Only a very small area of Franciscan-like rocks is

included in the Salinas Valley drainage basin, and at a great distance from the river mouth (Yancey, 1968). Galehouse (1967) investigated provenance of the sedimentary Paso Robles Formation which is located in the upper reaches of the Salinas River drainage area. He reported the heavy mineral compositions of this formation to be high in sphene, hornblende, garnet, epidote, apatite and zircon. This formation is also found outcropping east of the City of Monterey (California Dept. of Water Resources, 1970).

2. Sediment Transport Mechanisms

Heavy mineral assemblages are influenced by sediment transport mechanisms in the bay as well as by geological considerations in the drainage areas tributary to the bay. Littoral drift, offshore drift and other mechanisms tend to redistribute sediments.

In the southern portion of the bay, Dorman (1968) classified the sediments into five district subregions on the basis of depositional environment. They were: (a) the peninsular region, characterized by locally derived sediments and very little active transportation or deposition, (b) the sandy east coast region, characterized by predominantly southward weak longshore drift transport with heavy wave action and much near shore sediment diffusion, (c) the essentially non-depositional region in the southern end of the bay, with slow water movements and anomalous patterns of bottom type, (d) the confluence region or nodal area, characterized by the convergence of long-shore transport from both north and south and by some offshore movement, and

(e) the offshore region with little active sediment movement. These areas are shown schematically in Fig. 3. Dorman further indicated seasonal variation in the eastern longshore drift.

Yancey (1968) concluded that there is an eastward flow of sand into the inner portions of Monterey Bay along the north and south margins of the bay as littoral drift, with a section in the northeast sector having a southward drift. Although the Monterey Canyon cuts off a good deal of sediment transport from north to south, some sand can pass the head of the canyon without being lost from the nearshore sand budget.

C. PREVIOUS INVESTIGATIONS

Past investigations were conducted of the submarine geology of Monterey Bay by Galliher (1932), during which a general study was made of the nature of the sediments of the continental shelf of Monterey Bay.

Hutton (1959) conducted a very extensive study of the heavy mineral assemblages in the beach sands from Halfmoon Bay to the north to Pacific Grove, located at the south end of Monterey Bay. He directed his study toward the identification rather than the provenance of heavy minerals.

Wilde (1965) studied the recent sediments of the Monterey deep-sea fan. He concluded that the sands on the fan were from local sources near the head of the Monterey Submarine Canyon and that the finer sediments were derived locally and from the numerous valley drainages into San Francisco Bay via longshore drift. In addition, he concluded from

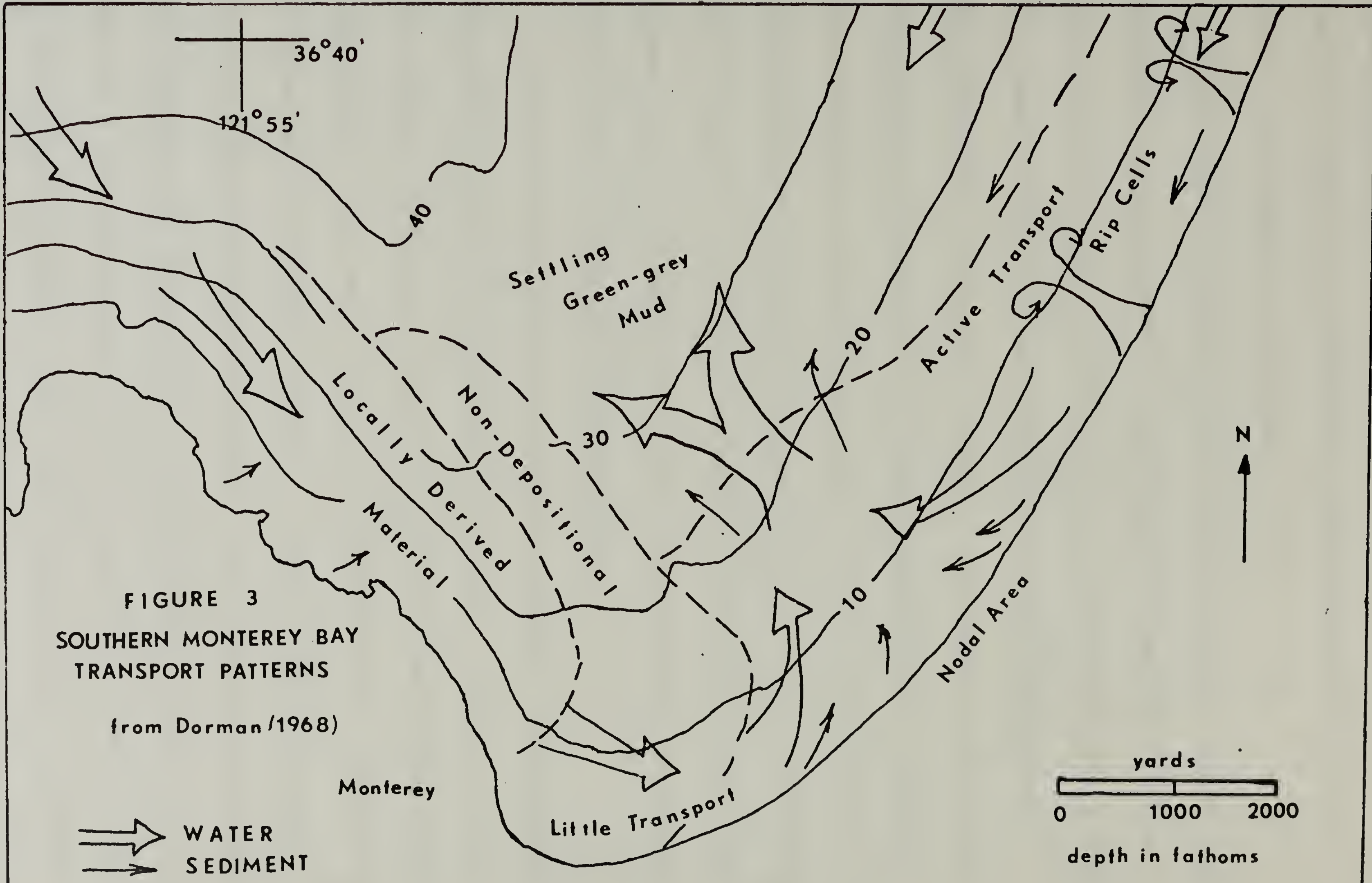


FIGURE 3
SOUTHERN MONTEREY BAY
TRANSPORT PATTERNS

(from Dorman /1968)

seismic profiles as well as sedimentary analyses, that formation of the Monterey fan began in pre-Pleistocene to post-Mesozoic time and probably in the Oligocene or Miocene.

Sayles (1966) undertook a study of heavy minerals in beach sands of Monterey Bay to determine the littoral transport patterns and their relation to present conditions. This was accomplished by grouping into heavy mineral suites those heavy minerals of similar composition, thereby delineating sedimentary provinces. In general he showed that Monterey Bay is separated into two heavy mineral suites, hornblende-augite-hypersthene and hornblende-garnet, and that these distinct suites are separated by the Monterey Submarine Canyon. Sayles further concluded that no long-term net littoral transport exists along most of the Monterey Bay beaches and that the pattern observed today has carried over from the last period of lowered sea level.

Yancey (1968) studied extensively the sediments of Monterey Bay and divided them into five heavy mineral provinces. Table I lists the heavy mineral composition near the mouths of the streams flowing into Monterey Bay. Other samples further up the streams were analyzed by Yancey but are not included in Table I. Two of the provinces were traceable to the Salinas and Pajaro Rivers, while the other three were not traceable to any single source. He noted that the Salinas River sediments had a high garnet content while the minerals glaucophane and lawsonite distinguished the Pajaro River sediments. The San Lorenzo River sediment has a mineral composition that is high in garnet but low

Table I

River Bed Heavy Mineral Counts*

Mineral	Sample Name and No.			
	San Lorenzo River, 1915	Soquel Creek, 1929	Pajaro River, 1949	Salinas River, 1972
Green Hornblende	51	30	41	56
Brown Hornblende	1	6		13
Oxyhornblende	5	7	4	1
Augite	25	28	27	8
Hypersthene	9	23	15	3
Epidote	2		4	1
Garnet	4	2		9
Sphene	3	2	3	5
Zircon				3
Apatite				1
Clinozoisite			1	
Glaucophane		2	4	
Lawsonite			1	

*from Yancey (1968)

in augite. This composition does not extend far beyond the mouth of the river.

He delineated sediment types in the bay which occur in three widespread bands that are aligned subparallel to the submarine contours. The sediments vary in age from a relict deposit of Pleistocene age in the outermost band at the edge of the continental shelf, to a middle band of Holocene age in the middle continental shelf, and thence to an inner band along the shoreline part of which may be mixed in age and part of modern origin off the mouths of the Salinas and Pajaro Rivers. Yancey (1971, personal communication) stated that the mineralogic trends near the mouth of the Salinas River that were outlined in his 1968 paper continue to the south in parallel alignment. He also stated that the beach samples from the Monterey Harbor area suggest a distinct mineral suite that is different from the Salinas River mineral suite.

II. PROCEDURES

A. TEXTURAL ANALYSIS

From the previously-conducted textural analyses performed by Hermann (unpublished data), a sample was taken of each sediment type or at each textural change in the core. Where no changes were readily apparent, samples were taken at least every meter down the core. These samples were desalinated and disaggregated. The coarse fraction was separated into 0.5 Φ intervals and weighed. Statistical parameters were computed for each sample and these appear in Tables II, III, and IV. Lithologic logs and photographs of the cores analyzed for heavy minerals appear in Appendix A. The sand-silt-clay relationships for each core are shown in Fig. 4, 5, and 6.

B. HEAVY MINERAL ANALYSIS

From the group of aforementioned cores, Stations 10, 14, and 18 were selected for heavy mineral analysis, and samples to be analyzed were taken from the top, middle and bottom of these cores. The samples were split where necessary, prior to heavy mineral separation, in order to insure that the total weight of the sample was less than 2 g for ease of handling. The heavy minerals were separated out of the fine and very fine sand sizes (2.5 to 4.0 Φ) in 0.5 Φ intervals using bromoform (specific gravity = 2.85) (Table V). The samples were then mounted in Lakeside 70 on a glass slide for analysis with a petrographic microscope.

Table II

Santa Cruz Area Core Analysis

Sample	Depth in core, cm	Mean*	Deviation*	Skewness*	Kurtosis*	% Sand	% Silt	% Clay	Description**
10-A	100	3.777	0.781	0.501	2.777	82	15	3	Sand
10-B	200	4.213	1.400	0.636	1.825	58	35	7	Silty Sand
10-C	300	4.140	1.249	0.686	3.058	72	22	6	Silty Sand
10-D	400	4.477	1.703	0.710	2.168	52	39	8	Silty Sand
10-E	500	4.517	1.968	0.597	2.086	57	34	9	Silty Sand
10-F	600	3.623	1.835	0.165	4.025	78	16	6	Sand
10-G	620	3.530	1.897	0.070	3.748	79	15	6	Sand

* Folk and Ward (1957) size parameters

** Shepard (1954)

Table III

Moss Landing Area Core Analysis

Sample	Depth in core, cm	Mean*	Deviation*	Skewness*	Kurtosis*	%Sand	% Silt	% Clay	Description**
14-A	0	one large rock comprises entire sample							
14-B	0	-0.367	1.521	0.062	1.296	Not analyzed for			Sand
14-C	100	0.090	1.150	-0.197	0.786	silt and clay			Sand
14-D	150	0.483	0.750	-0.048	1.104	"			Sand
14-E	200	0.160	0.982	-0.142	0.916	"			Sand
14-F	300	very coarse pebbly sand; not analyzed							
14-G	340	3.513	1.141	0.496	5.247	85	7	7	Sand
14-H	400	3.767	1.536	0.702	4.571	80	12	7	Sand
14-I	500	3.487	0.883	0.495	2.980	84	11	5	Sand
14-J	628	3.777	1.596	0.721	4.005	78	14	7	Sand

* Folk and Ward (1957) size parameters

** Shepard (1954)

Table IV

Monterey Area Core Analysis

Sample	Depth in core, cm	Mean*	Deviation*	Skewness*	Kurtosis*	% Sand	% Silt	% Clay	Description**
18-A	0	1.297	0.493	0.038	1.135	99	0	0	Sand
18-B	50	1.393	0.721	0.148	1.674	96	2	2	Sand
18-C	100	1.283	0.579	0.087	1.230	99	0	0	Sand
18-D	210	2.640	0.849	-0.293	2.215	95	2	2	Sand
18-E	300	3.030	0.403	0.192	1.180	97	1	2	Sand
18-F	335	3.010	0.665	-0.286	2.196	95	3	2	Sand
18-G	400	3.003	0.442	0.141	1.260	96	2	2	Sand
18-H	550	2.117	1.042	0.050	1.517	94	4	2	Sand

* Folk and Ward (1957) size parameters

** Shepard (1954)

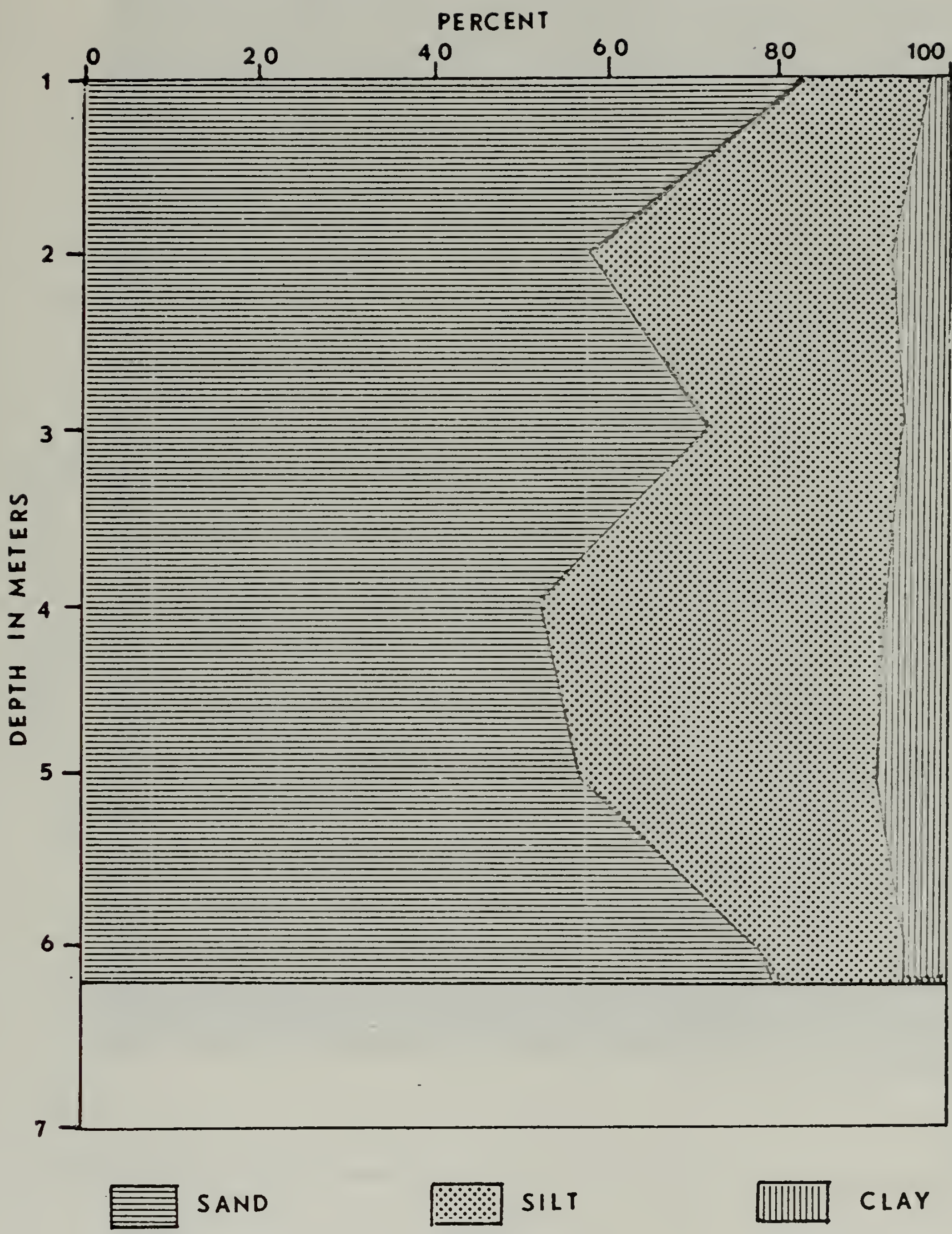


FIGURE 4 SAND/SILT/CLAY COMPOSITION OF CORE 10

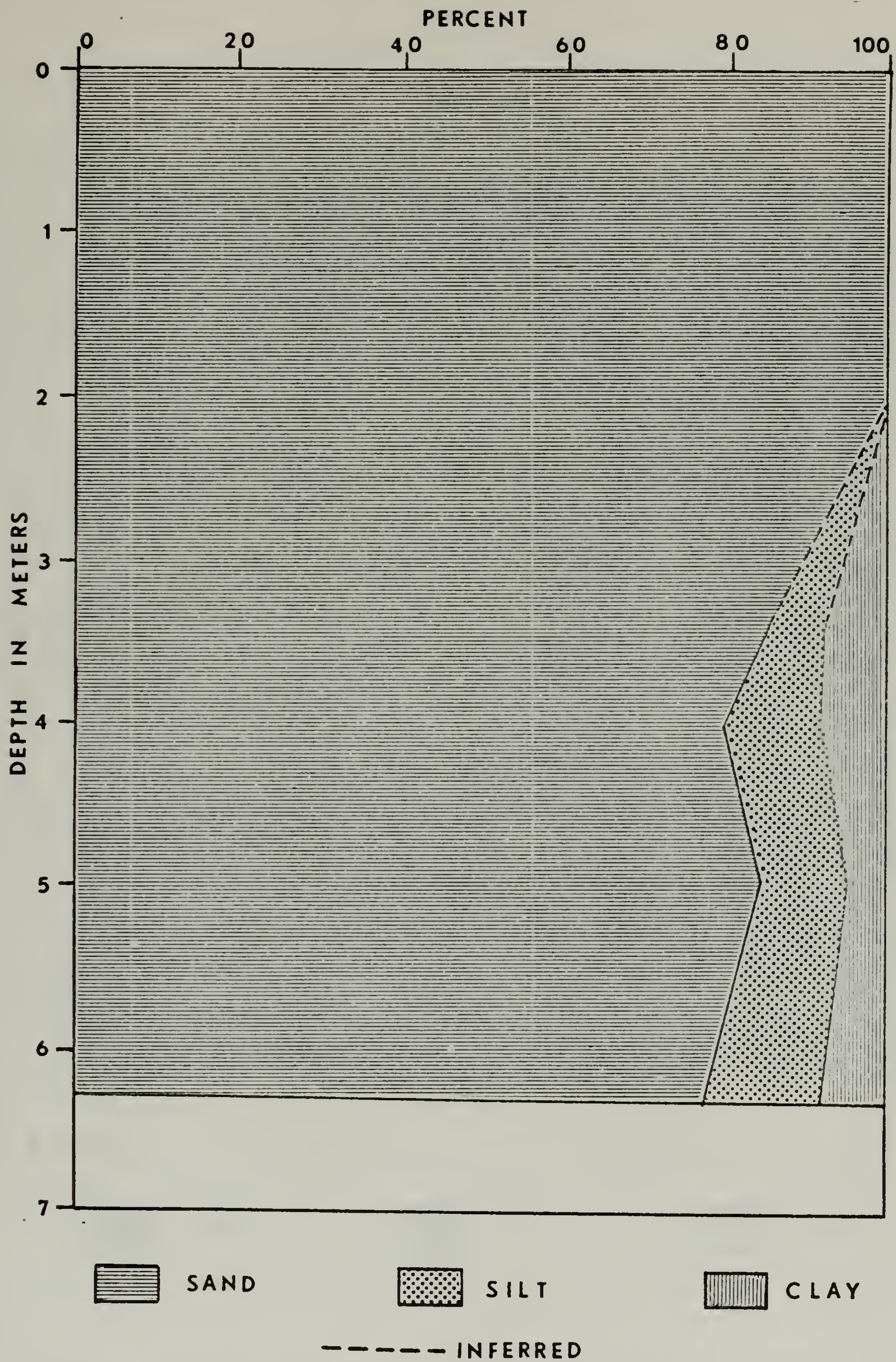


FIGURE 5 SAND/SILT/CLAY COMPOSITION OF CORE 14

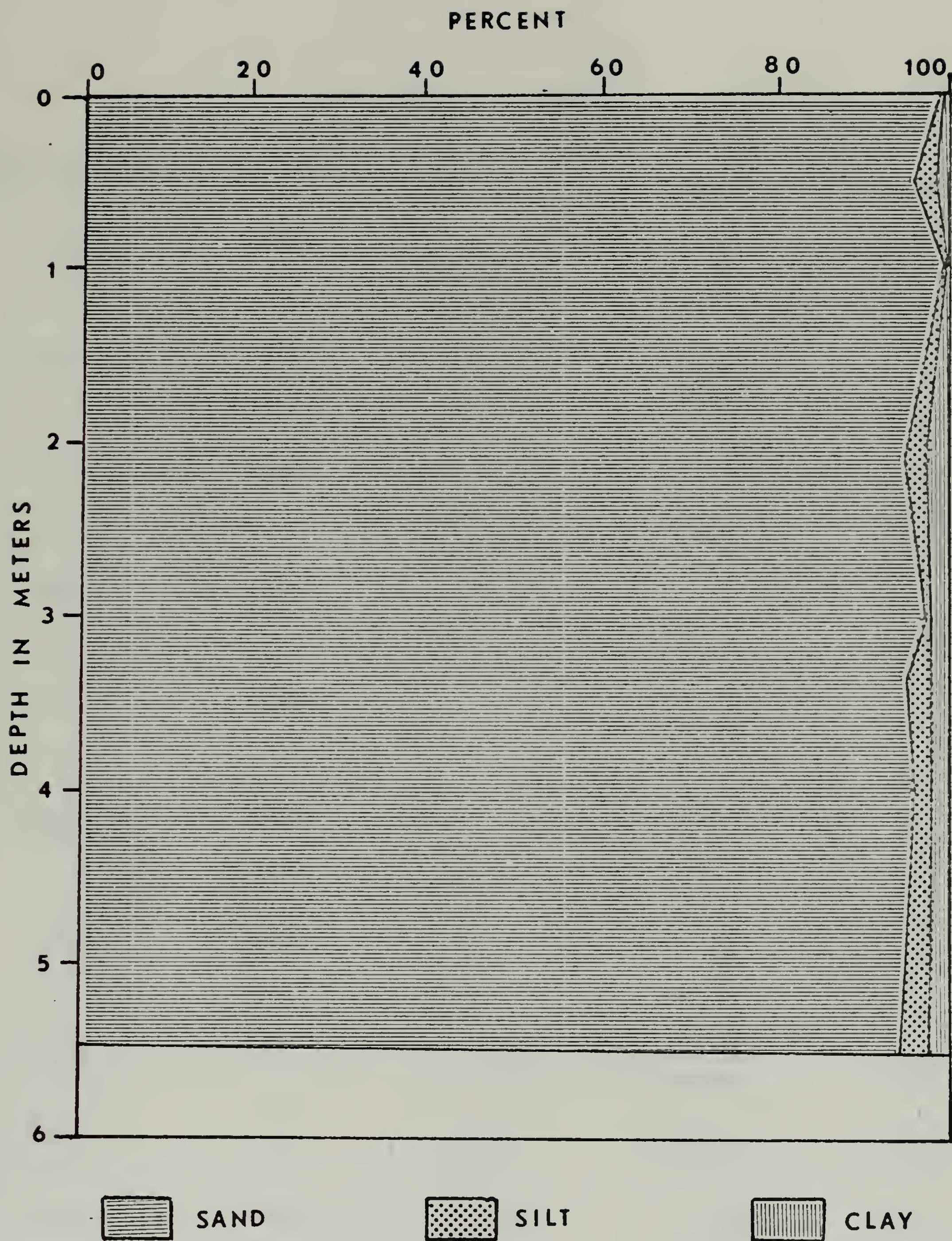


FIGURE 6 SAND/SILT/CLAY COMPOSITION OF CORE 18

Table V

Heavy Mineral Content

Core Sample	Sample Depth (cm)	Phi Size	Percentage Light	Percentage Heavy
10A*	100	2.5-3.0	94.88	5.12
		3.0-3.5	95.86	4.15
		3.5-4.0	97.12	2.88
10B	200	2.5-3.0	92.74	7.26
		3.0-3.5	98.60	1.40
		3.5-4.0	98.00	2.00
10C*	300	2.5-3.0	89.00	11.00
		3.0-3.5	98.10	1.90
		3.5-4.0	98.51	1.49
10D	400	2.5-3.0	NO DATA	
		3.0-3.5	98.16	1.84
		3.5-4.0	98.42	1.58
10E	500	2.5-3.0	90.78	9.22
		3.0-3.5	96.77	3.23
		3.5-4.0	98.21	1.79
10F	600	2.5-3.0	91.44	8.56
		3.0-3.5	98.41	1.59
		3.5-4.0	98.50	1.50
10G*	620	2.5-3.0	89.85	10.15
		3.0-3.5	97.49	2.51
		3.5-4.0	98.19	1.81
14B*	0	2.5-3.0	61.23	38.77
		3.0-3.5	79.39	20.61
14C	100	2.5-3.0	43.45	56.55
		3.0-3.5	74.85	25.15
14D	150	2.5-3.0	91.45	8.55
		3.0-3.5	74.47	25.53
14E	200	2.5-3.0	88.15	11.85
		3.0-3.5	86.57	13.43
		3.5-4.0	64.17	35.83
14G*	340	2.5-3.0	95.13	4.87
		3.0-3.5	96.74	3.26
		3.5-4.0	95.10	4.90

Table V

Heavy Mineral Content (cont.)

Core Sample	Sample Depth (cm)	Phi Size	Percentage	
			Light	Heavy
14H	400	2.5-3.0	96.94	3.06
		3.0-3.5	97.34	2.66
		3.5-4.0	91.32	8.68
14I	500	2.5-3.0	96.83	3.17
		3.0-3.5	96.38	3.62
		3.5-4.0	92.41	7.59
14J*	628	2.5-3.0	97.72	2.28
		3.0-3.5	97.69	2.31
		3.5-4.0	93.51	6.49
18A*	0	2.5-3.0	85.64	14.36
		3.0-3.5	88.27	11.73
		3.5-4.0	73.18	26.82
18B	50	2.5-3.0	89.35	10.65
		3.0-3.5	94.37	5.63
		3.5-4.0	93.12	6.88
18C	100	2.5-3.0	92.27	7.73
		3.0-3.5	89.46	10.54
		3.5-4.0	89.55	10.45
18D*	210	2.5-3.0	96.82	3.18
		3.0-3.5	88.81	11.19
		3.5-4.0	78.90	21.10
18E	300	2.5-3.0	97.09	2.91
		3.0-3.5	91.81	8.19
		3.5-4.0	82.97	17.03
18F	335	2.5-3.0	95.50	4.50
		3.0-3.5	91.70	8.30
		3.5-4.0	84.78	15.22
18G	400	2.5-3.0	97.42	2.58
		3.0-3.5	87.72	12.28
		3.5-4.0	81.73	18.27
18H*	550	2.5-3.0	96.57	3.43
		3.0-3.5	85.59	14.41
		3.5-4.0	86.83	13.17

* Samples analyzed petrographically.

One hundred nonopaque, nonmicaeous and noncomposite heavy mineral grains of each sample fraction were counted by line count method (Table VI). Mineral grains identified in a scan of the slide which were not among the 100 grains counted were listed as trace minerals. Mica, opaque and composite grains were counted and tabulated separately (Table VII). A recount was made of all the samples at a later time to assure accuracy of the initial counts.

An attempt was made, by use of tertiary diagrams, to determine whether distinctive relationships between mineral amounts could be recognized for any of the cores. No distinctive mineral suites were identified. The tertiary diagrams are shown in Fig. 13, 14, 15, and 16 in Appendix B.

Mineral identification was accomplished by optical means using a petrographic microscope. Color, pleochroism, crystal habit, cleavage traces, extinction angle, relief, birefringence and interference figure were all utilized in order to identify mineral grains. In all cases, the counts tabulated represent the 3.5 to 4.0 Φ size sample. The 2.5 to 3.0 Φ and 3.0 to 3.5 Φ samples were used for initial identification of common heavy minerals in a slide, for ease in identifying the minerals in the 3.5 to 4.0 Φ sample.

Kerr (1959) presents a useful series of keys for identification of heavy minerals, and Hutton (1959) considered local variation in characteristics of some heavy minerals examined in this study area.

Table VI

Heavy Mineral Percentages

Mineral	Sample No. (Depth, cm)								
	10A (100)	10C (300)	10G (620)	14B (0)	14G (340)	14J (628)	18A (0)	18D (210)	18H (550)
Andalusite								2	
Apatite	4	5	6	4	7	7	5	7	4
Augite	30	25	24	23	13	13	18	17	40
Clinozoisite	1							1	
Epidote	2	5	4	5	5	7	4	1	1
Garnet	2	TR	4	4	13	9	9	9	TR
Glaucophane			1		TR	1		1	TR
Green Hornblende	41	36	38	39	43	38	30	26	11
Brown Hornblende	5	7	5	6	9	10	12	2	3
Hypersthene	15	21	15	14	5	6	13	21	40
Kyanite								1	
Rutile				1				1	
Sillimanite								2	
Sphene		1	3	4	4	7	5	3	1
Zircon		TR	TR		1	2	4	6	TR

Note: TR (trace) is less than 1.0% of heavy mineral fraction.

Table VII

Counts of the Constituents in the Heavy Mineral Fraction

Mineral	Sample No. (Depth, cm)								
	10A (100)	10C (300)	10G (620)	14B (0)	14G (340)	14J (628)	18A (0)	18D (210)	18H (550)
Opaques	26	13	7	22	6	9	16	17	17
Composites	23	16	20	23	21	13	24	25	23
Biotite	29	3	7	10	8	7	8	25	6
Other Micas	45	21	9	28	24	4	68	19	11
Table VI	100	100	100	100	100	100	100	100	100
Total Count	223	153	143	183	159	133	216	186	157

III. TEXTURAL AND HEAVY MINERAL ANALYSES

A. MINERAL DESCRIPTION

1. Major Constituents

Hornblende, augite, hypersthene and garnet represent the major constituents of the heavy mineral fraction. Hornblende was found extensively in all the samples examined. Green hornblende predominated over the brown variety. Both varieties were observed to exist as irregularly fractured grains, the brown being slightly more rounded. The green variety showed well-defined striations and varied in color from medium to dark forest green. Pleochroism was very marked in the green variety. Coloring in the brown variety varied from light yellow-brown to deep red-brown.

Augite was well distributed in all the cores. The grains were colorless to pale green and usually clear and free of inclusions. Nearly all the grains examined had numerous needle-like or spear-shaped endings indicating solution alteration.

Hypersthene was identified in all the surface samples but varied greatly in quantity with depth. In all cases, the distinctive pleochroism from rose-pink to pale green was evident and was the major identifying characteristic. The grains varied in shape from a columnar habit to a semirounded shape, with numerous grains showing spear-shaped endings as in the case of augite. A distinctive change of

habit from columnar with slight end alteration to semirounded habit was noted with increasing depth in all cores.

Garnet was found in moderate amounts, which generally increased from the Santa Cruz core to the Monterey core. The grains were identified by their distinctive high relief and semi-conchoidal fracture surfaces. Two pink garnets were found in sample 18A, one in 14G and a trace in sample 14J. The grains were predominantly sub-angular to sub-rounded with high sphericity. Inclusions were present in most of the grains.

2. Minor Constituents

Small amounts of apatite were identified in all samples. The grains were colorless, clear of inclusions and euhedral in habit.

Sphene was found in varying quantities in the cores and was in all cases yellow-brown in color with slight pleochroism. A few grains showed incomplete extinction, and a good interference figure was obtained in only one case. The main identifying characteristics were the high-order yellowish-white interference color and the high relief.

Epidote and clinozoisite appeared in all samples. Epidote grains were both light and dark green in color with only slight pleochroism. The surface of the grains was very granular. The clinozoisite grains were colorless and exhibited a very low extinction angle.

Zircon, although found in small quantities, was distinctively characterized by cigar-shaped smooth grains with very high relief and common inclusions. Anomalous biaxial interference figures were obtained in several cases.

Glaucophane was distinctively pale blue in color with pleochroism to violet. These grains exhibited the typical amphibole habit with cleavage traces prominant.

Rutile was distinguished by an adamantine luster under reflected light and very deep red-brown coloration which almost qualified the grains as opaque constituents of the sample.

B. QUANTITATIVE RESULTS

Heavy mineral contents tend to decrease with depth in all three cores (Table V).

Hornblende, augite, hypersthene and garnet accounted for 75% cf all the samples. Hornblende alone accounted for approximately 30 to 50% in all cases, except in samples 18D and 18H. Augite maintained a relatively constant percentage except in sample 18H. A general increasing trend in garnet was noted toward the south of Monterey Bay with the exception of 18H. Hypersthene remained substantially constant in all samples except for notably lower percentages in 14G and 14J and an extremely high anomalous value in 18H.

Cores 14 and 18 were garnet rich, while cores 10 and 18 were hypersthene rich. Glaucophane was found in all cores below the surface sample.

1. Santa Cruz Area Core

The distribution of heavy minerals in Core 10 is substantially uniform with depth. In general, the distribution compared closely with that found by Yancey (1968) in his Province 4, except for slightly

higher augite percentages. Glaucophane was found at the bottom of this core in small amounts. Biotite and other micas as well as opaques generally decreased with depth in this core.

Core 10 was visually uniform in composition, a poorly-sorted sand or silty sand, except for the surface sample which was moderately-sorted sand.

2. Moss Landing Area Core

The surface sample of Core 14 differed slightly in heavy mineral composition from the deeper samples of that core. Augite and hypersthene percentages were notably greater at the surface, while the garnet percentage was less at the surface. Small amounts of glaucophane were noted. This core was somewhat richer in garnet in comparison with the other cores. Biotite and other micas as well as opaques decreased with depth.

Core 14, composed of moderately- to poorly-sorted sand, varied greatly in appearance with depth, as can be observed in the photograph and field description (Appendix A).

3. Monterey Area Core

The percentage of heavy minerals in the 3.5 to 4.0 Φ range was notably higher in this core than the others analyzed.

The total amount of hornblende decreased with depth. A large difference in the relative amounts of garnet, hypersthene and augite was dramatically evident in the bottom sample of this core. Augite and hypersthene together composed 80% of this bottom sample.

Garnet decreased from a constant percentage near the surface to a trace in the bottom sample. Hypersthene showed an anomalously high percentage in sample 18H. Glaucophane occurred in small amounts in this core. Mica decreased in percentage with depth.

Sample 18H was noted to be anomalously poorly-sorted (Table IV) relative to the rest of the overlying sediment in the core, which varied from well-sorted to moderately-sorted sand.

IV. DISCUSSION

The heavy mineral distribution with depth in the various samples could not be classified into any distinctive mineral suites. The samples containing glaucophane were in part derived from the Franciscan formations of the Pajaro River drainage area. The Salinas River drainage area, on the other hand, contains small exposures of this formation so that the amount of glaucophane transported to the bay is probably not significant due not only to the small size of the Franciscan formation areas in proportion to the whole Salinas River basin but also to the extreme distance of these formations from the bay. Sediment samples derived from the Salinas River contain minerals common to all drainage areas (Table I) and, if mixed with sediments from another source, the relative amounts of garnet and brown hornblende needed to distinguish the Salinas source would be reduced.

The distribution in the Santa Cruz area core was not indicative of any one source area but most probably was a locally derived mixture with some augite enrichment by longshore drift from a northern province found to be augite-rich by Yancey (1968). The presence of glaucophane at depth in this core may indicate the influence of the Pajaro River source area at a prior time, although Yancey found small amounts of glaucophane in almost every sample in the northern part of the bay.

The Moss Landing area core showed influences of both the Pajaro and Salinas Rivers. The small amounts of glaucophane noted were

indicative of the Pajaro River outflow. Relatively larger amounts of garnet with depth may be indicative of the period of influence of the Salinas River flowing out at Elkhorn Slough. The decrease of augite slightly with depth again may also be indicative of the prior influence of the Salinas River, which is low in augite relative to the Pajaro River (Table I). The varying compositional textures indicate multiple and dynamic influences on the deposition in this area.

Core 18 is located in an area influenced geologically by both the Salinas River source and the local granitic sources on the tip of the Monterey Peninsula. The influence of the Salinas River sediments can be distinguished in the relatively high garnet content of the upper two samples. The high amount of hypersthene indicated a source of igneous or metamorphic rocks. In this area the Santa Lucia granodiorite, which outcrops along much of the Monterey Peninsula, could have contributed to the quantity of hypersthene but probably not in this large a percentage. A large source of metamorphics exists in the nearcoast portion of the Salinas River drainage basin. Considering both the depth of the sample in the core and the water depth (146 ft), a possible source of the high pyroxene content (augite and hypersthene) in the bottom sample could be a relict beach deposit from a period of lower sea level. Glaucophane in small amounts in this southern core suggests transport of the Pajaro River sediments to this area.

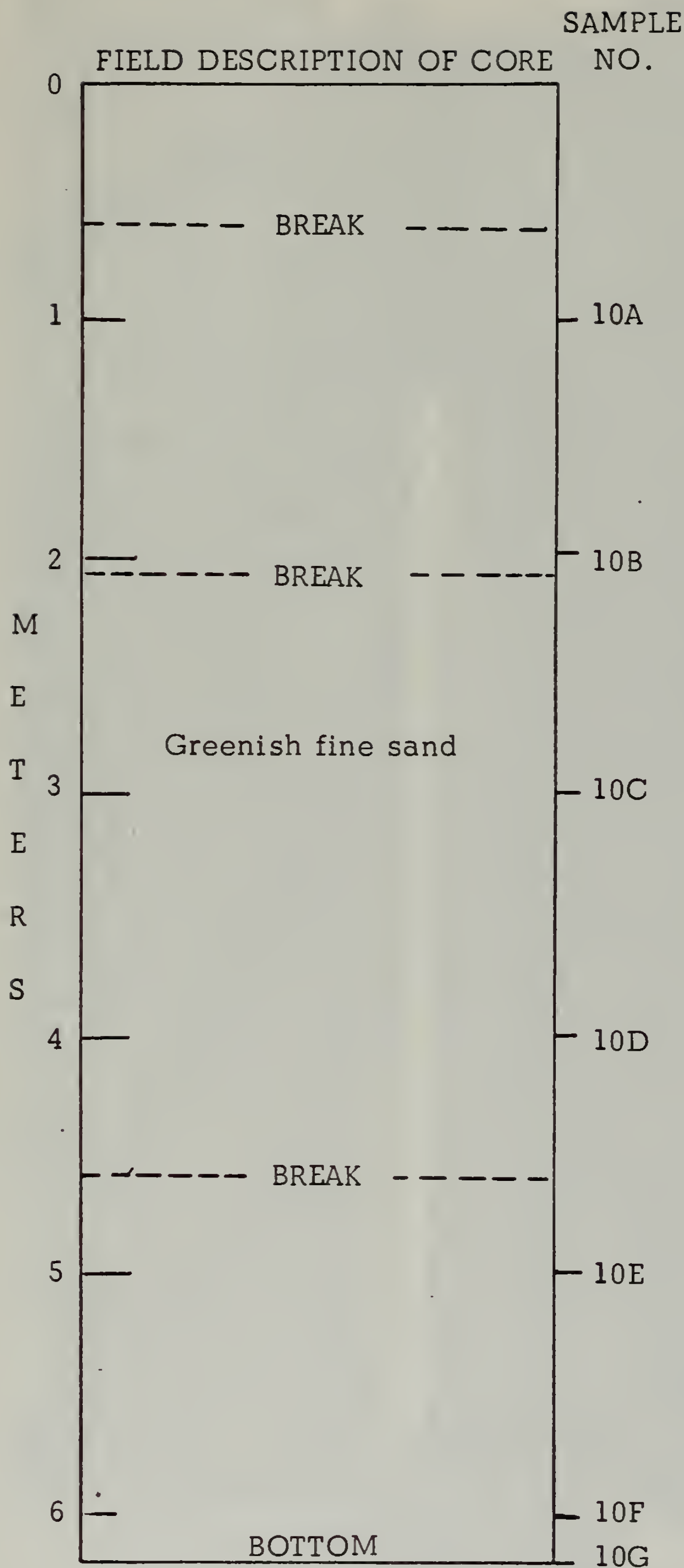
V. FUTURE WORK

This study, of necessity, has been limited in scope and has not covered the entire spectrum of compositional changes in heavy mineralogy with depth in the cores examined. More complete studies of these cores, correlated with similar studies of other cores taken in this group would yield not only more knowledge of the heavy mineralogy of the sediments but would lead to a better understanding of the sedimentary processes in Monterey Bay, both now and in the recent past.

In order to further delineate the heavy mineral provinces and the origin of sediment suites in the southern portion of the bay, a large number of core samples should be obtained and analyzed.

APPENDIX A

FIELD DESCRIPTIONS AND PHOTOGRAPHS OF CORES



CORE NO.: 10

LATITUDE: 36° 53.97'

LONGITUDE: 121° 59.49'

WATER DEPTH: 118 ft

CORER TYPE: VIBRO CORER

TOTAL LENGTH: 17 ft 6 in

REMARKS: Bottomed in sand. Penetration of 22 ft. Uniform core of greenish fine sand.

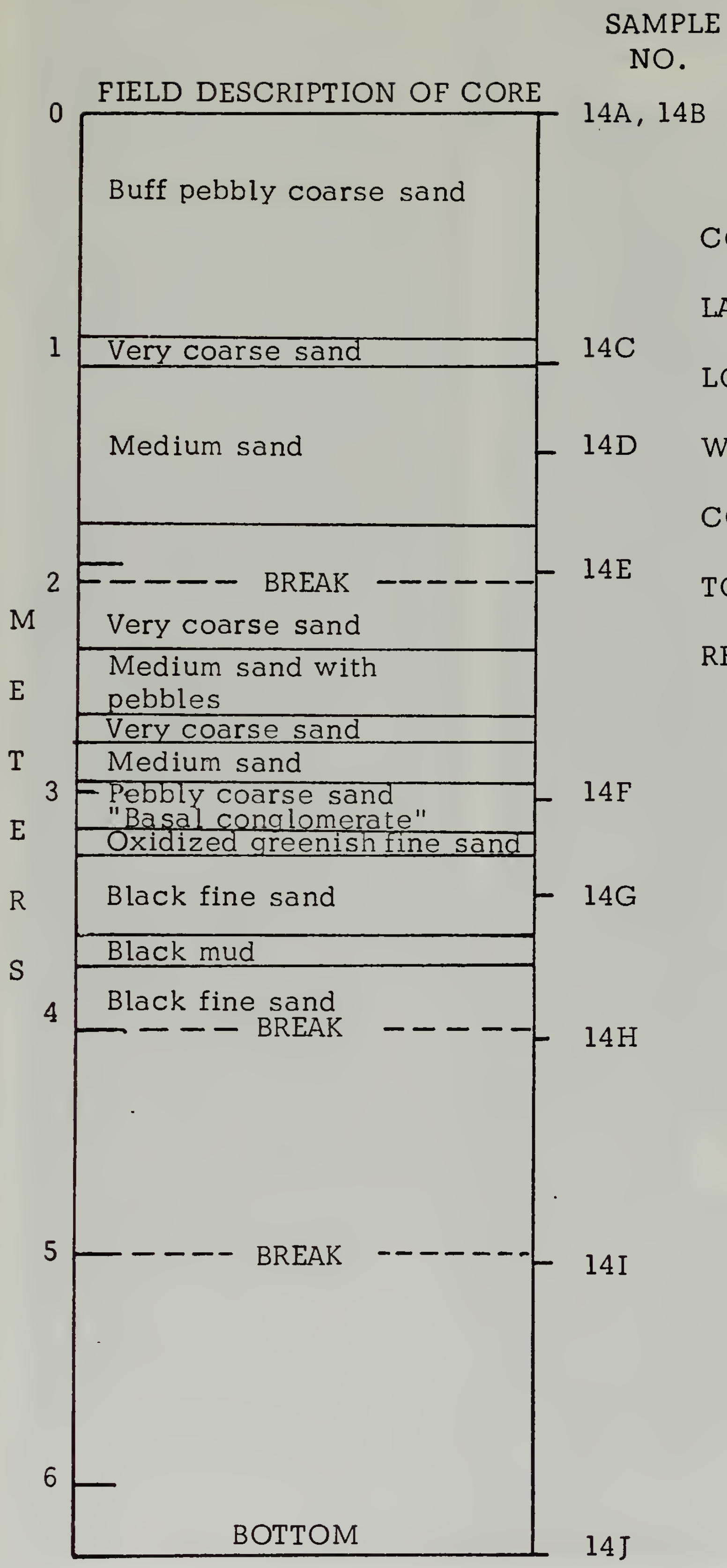
Core taken March 1, 1970

Core cut May 5, 1970

after Andrews and Hermann (unpublished data)

FIGURE 7 FIELD DESCRIPTION OF CORE 10

FIGURE 8 PHOTOGRAPH OF CORE 10



CORE NO.: 14

LATITUDE: 36° 45.63'

LONGITUDE: 121° 48.72'

WATER DEPTH: 106 ft

CORER TYPE: VIBRO CORER

TOTAL LENGTH: 21 ft 2 in

REMARKS: Bottomed in fine sand. Penetration of corer undetermined.

Sample 14A is large shale rock. First 3 meters appear to be beach sand.

Core taken March 2, 1970

Core cut May 5, 1970

after Andrews and Hermann (unpublished data)

FIGURE 9 FIELD DESCRIPTION OF CORE 14

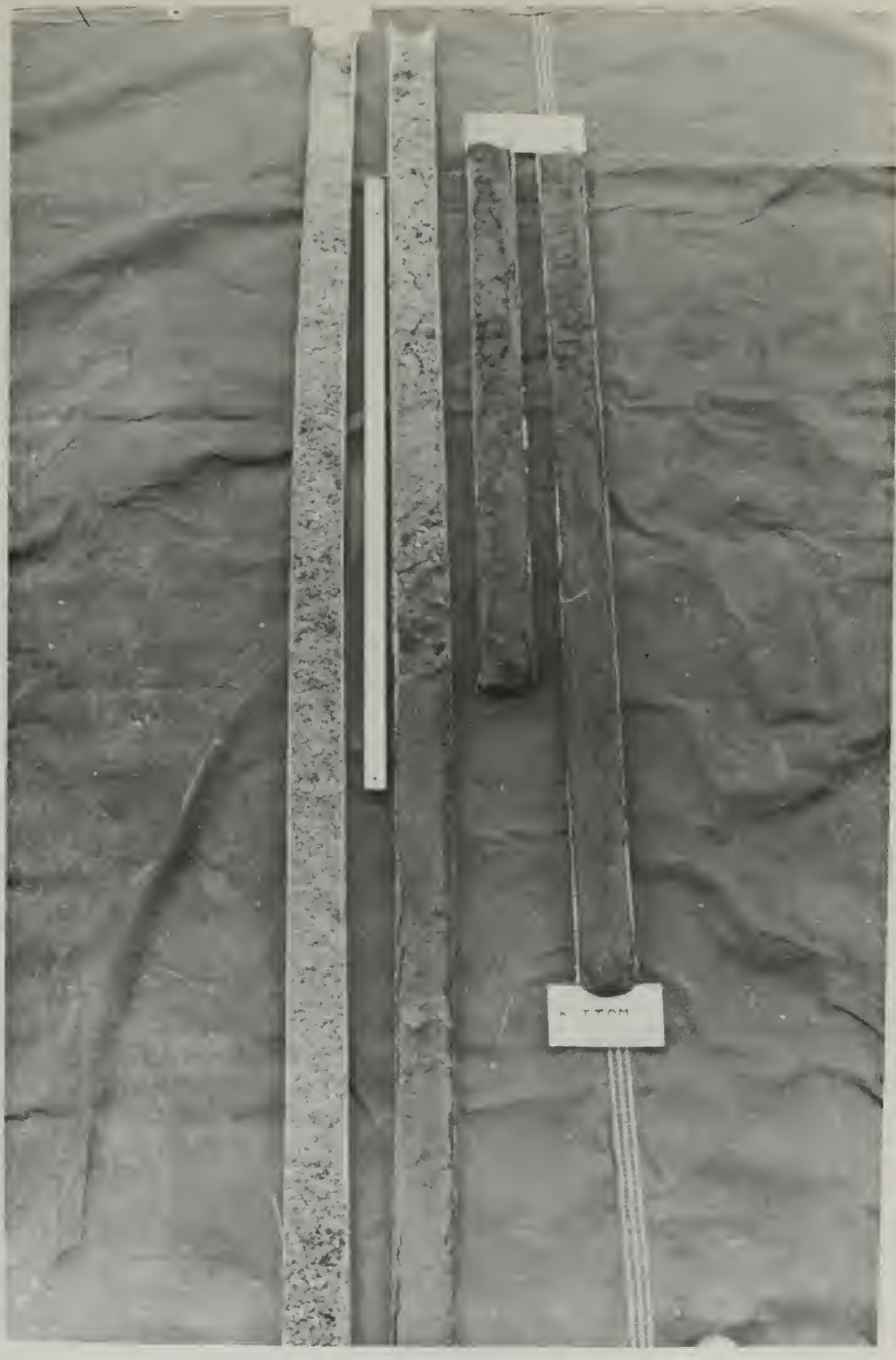


FIGURE 10 PHOTOGRAPH OF CORE 14

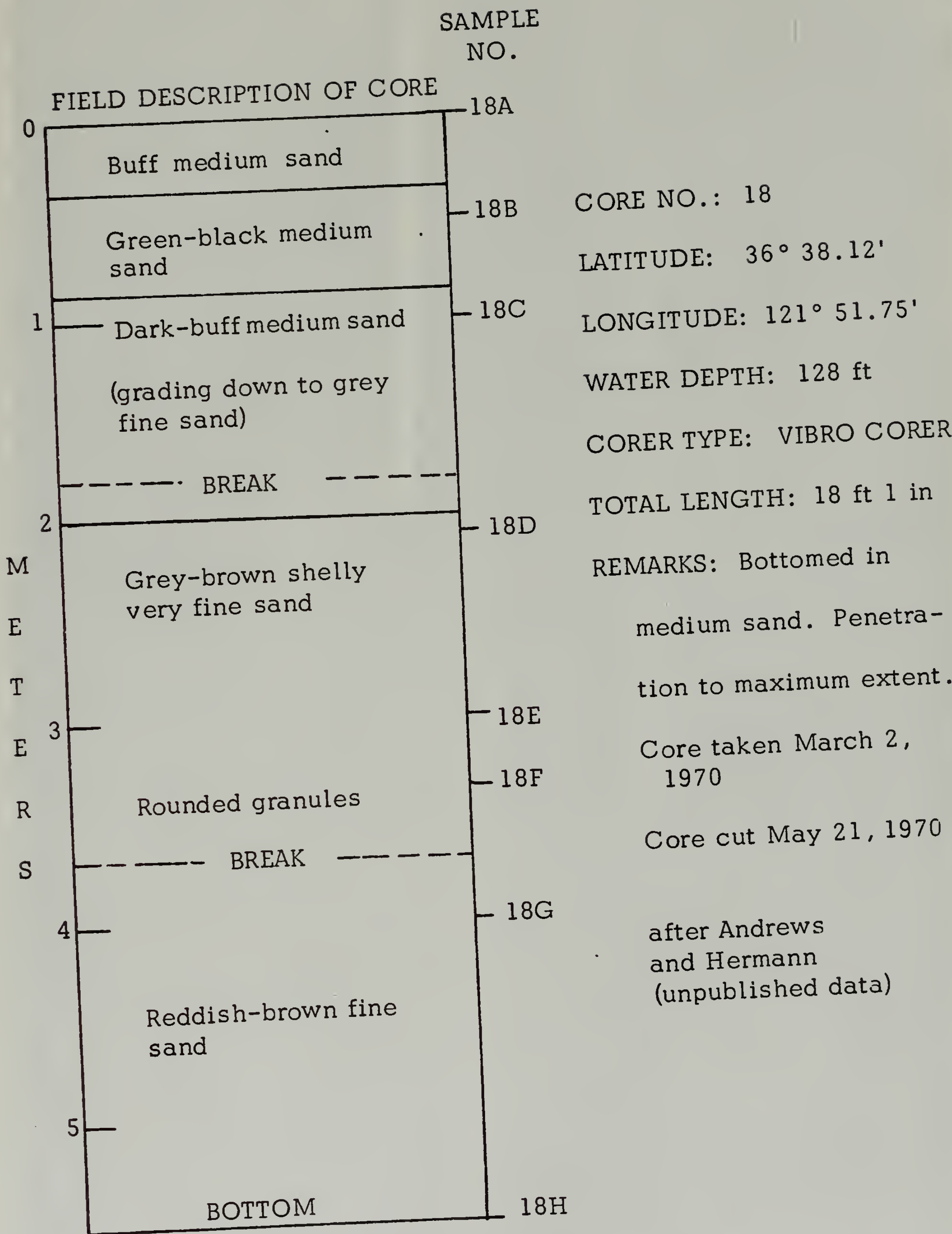


FIGURE 11 FIELD DESCRIPTION OF CORE 18

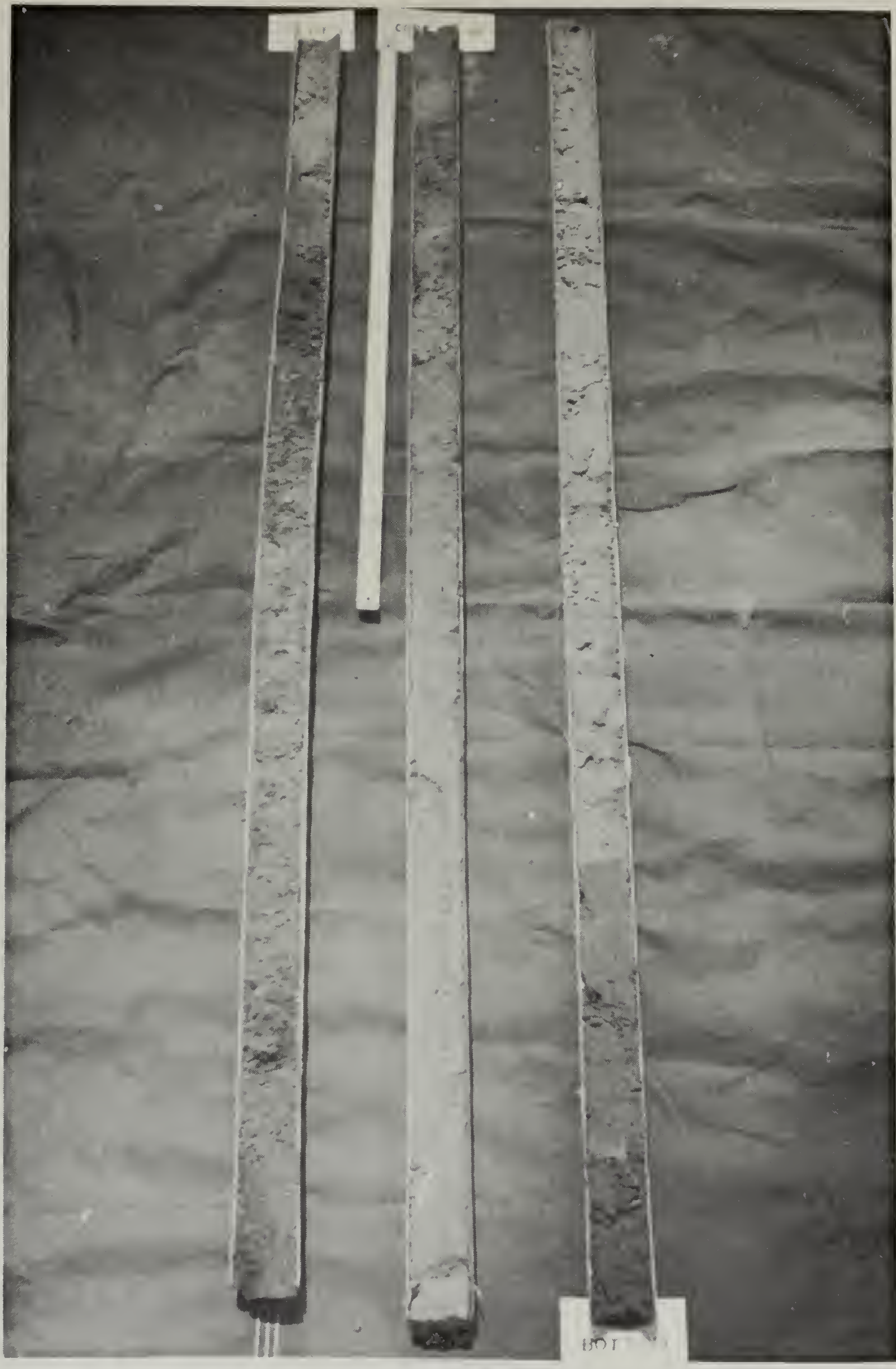


FIGURE 12 PHOTOGRAPH OF CORE 18

APPENDIX B

TERTIARY DIAGRAMS

1. Fig. 13 Tertiary Diagram: Hornblende/Augite/Hypersthene
2. Fig. 14 Tertiary Diagram: Hornblende/Augite/Zircon
3. Fig. 15 Tertiary Diagram: Hornblende/Opaques/Hypersthene
4. Fig. 16 Tertiary Diagram: Hypersthene/Opaques/Garnet

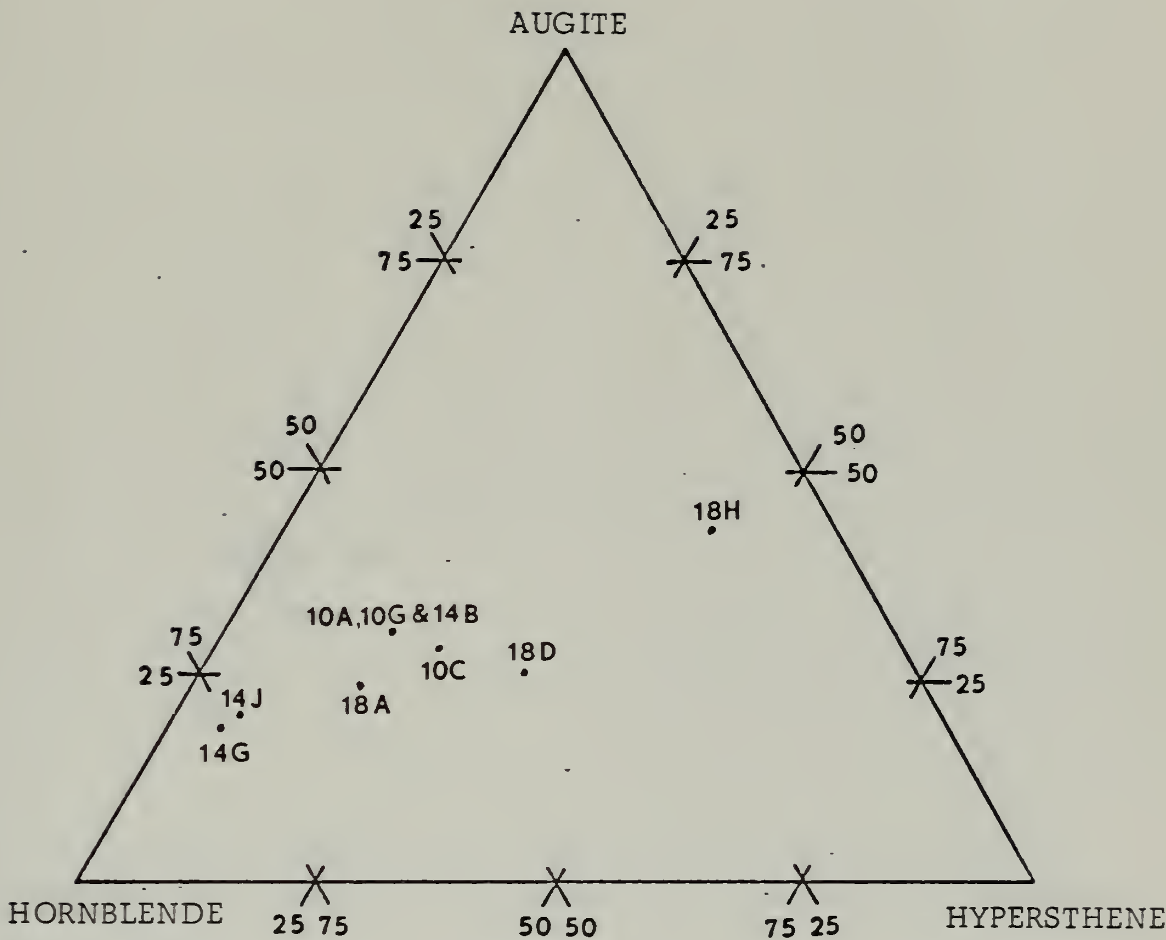


FIGURE 13 TERTIARY DIAGRAM
HORNBLENDE/AUGITE/HYPERSTHENE

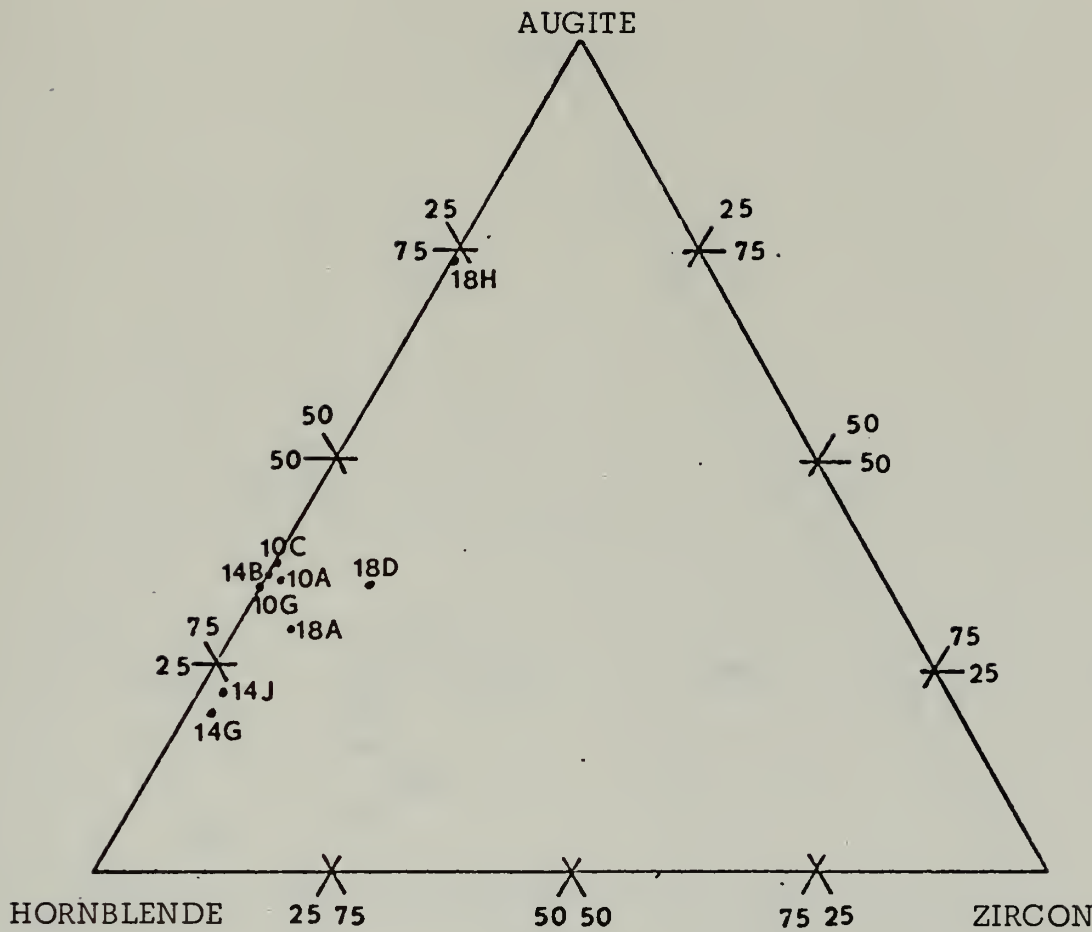


FIGURE 14 TERTIARY DIAGRAM

HORNBLENDE/AUGITE/ZIRCON

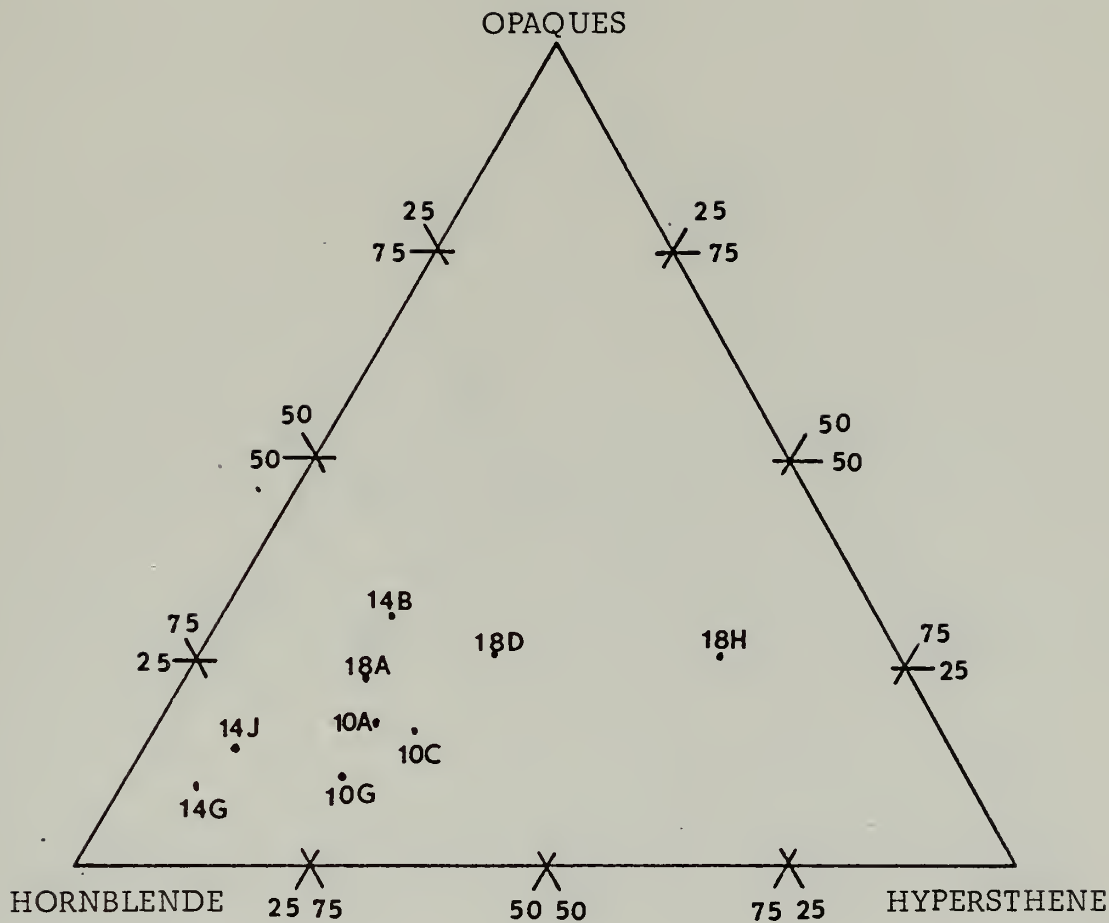


FIGURE 15 TERTIARY DIAGRAM

HORNBLENDE/OPAQUES/HYPERSTHENE

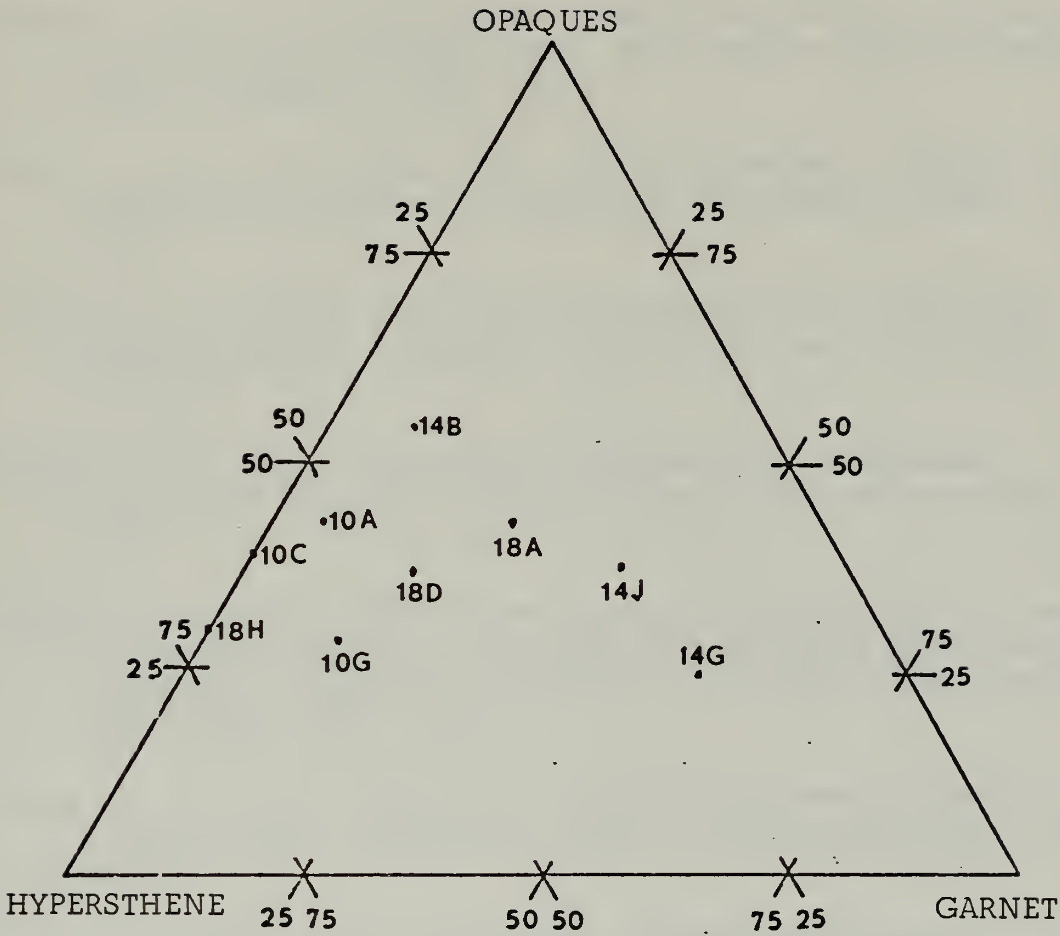


FIGURE 16 TERTIARY DIAGRAM

HYPERSTHENE/OPAQUES/GARNET

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13. ABSTRACT

This study was conducted to identify heavy minerals and their changes with depth in three cores taken from different locations in Monterey Bay, California. Monterey Bay provides an area where several different sources influence the sediment deposition.

Minerals indicative of the geological formations in the drainage areas of the Pajaro and Salinas Rivers were found in distinctive distribution throughout these cores. Glaucophane, indicative of the Franciscan Formation, was found near the bottom of all cores. The larger percentages of augite found in the core at Santa Cruz were probably derived from the north due to longshore drift. High percentages of garnet and low percentages of hypersthene with depth in the Moss Landing Core reflect the influence of the Salinas River.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Geological oceanography						
Heavy minerals						
Monterey Bay sediments						
Sediment cores						
Sediment size analysis						
Petrographic mineral analysis						

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